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Edited by Bill Travis

Circuit provides 4- to 20-mA loop for microcontrollers

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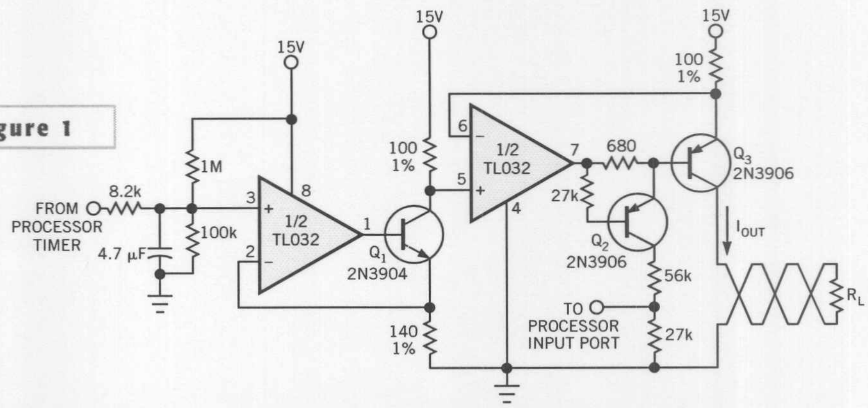
The 4- to 20-mA current loop is ubiquitous in the world of controls in manufacturing plants. Discrete logic, microprocessors, and microcontrollers easily cover the digital portions of control schemes, such as limit switches, pushbuttons, and signal lights. Interfacing a 4- to 20-mA output to a rudimentary microcontroller can be problematic. A built-in A/D converter would be nice, but such a device is sometimes unavailable in the "economy" line of these processors. Serial 4- to 20-mA chips exist but are relatively expensive and require serial programming and involve microcontroller overhead. Most lower end chips lack dedicated serial ports and require pin-programming.

This circuit is a low-cost alternative that provides not only a 4- to 20-mA output, but also a digital feedback signal that indicates an open wire in the current loop (**Figure 1**). One output-port pin sets the current, and one input-port pin monitors an open circuit in the loop wire. The circuit does not require the open-loop feedback portion of the circuit for the current loop to operate; you can omit it for further cost savings.

The circuit derives its drive from a simple timer output in the microcontroller. The duty cycle of the timer determines the output current of the circuit. The input RC network in front of the first operational-amplifier signal conditions the pulse train from the processor, so that the op amp interprets it as a dc voltage. In addition, the network ensures that the minimum input voltage is close to 100 mV, even if the input is at ground potential. This minimum voltage ensures that the feedback loop of the first op amp does not fold back to the positive rail when you cut off npn transistor Q_1. If you use a dual supply, the transistor has the additional voltage swing below ground potential to keep it in its active region and does not cut off. The emitter resistor of npn transistor Q_1 sets the current span of the circuit. With a 5V drive from the microcontroller, the output current is 20 mA. A grounded input results in less than 1 mA. A duty cycle of 12.5% drives the loop at 4 mA and exhibits linear control to full scale. Although it may not be mandatory, most current loops prefer a grounded return path. The purpose of the second operational amplifier is to provide a current source, rather than the current sink of the first stage, and the grounded return path. Hence, pnp transistor Q_3 provides this high-side drive. Bipolar-junction transistors Q_1 and Q_3 meet cost considerations, but you could also use MOSFETs for slightly better performance.

The open-loop feedback portion of this circuit lets the microcontroller know that a fault condition exists on the line. The processor can then execute alarm, shutdown, or other control functions to mitigate possible safety concerns. When an open-loop condition occurs, Q_3 shunts the entire loop current back through its emitter-base junction and through the 680Ω resistor to the op amp. The voltage developed across the 680Ω resistor turns on Q_2, resulting in a logic-one feedback to the microcontroller. Note that the open loop requires at least 1 mA of current for the open indication to function, which is below the normal 4 mA—a "zero" output condi-

Figure 1



This configuration provides both a 4- to 20-mA loop and an open-circuit indication.

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tion for this type of control system.

Response time for a step change is approximately 500 msec, which is acceptable for most current-loop control devices, such as control valves. If the microcontroller you select has a built-in A/D converter, response time can decrease by a couple of orders of magnitude with the elimination of the input-filtering network. Op-amp selection is important if you use a single-supply topology. An operational amplifier that can maintain stability close to its negative, or ground, rail is an important asset.□

Minimize the short-circuit current pulse in a hot-swap controller

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Because of internal circuit-breaker delay and limited MOS-gate pulldown current, many hot-swap controllers do not limit current during the first 10 to 50 μsec following a shorted output. The result can be a brief flow of several hundred amperes. A simple external circuit can counter this problem by minimizing the initial current spike and terminating the short circuit within 200 to 500 nsec. A typical 12V, 6A, hot-swap-controller circuit contains, as do many others, slow and fast comparators with trip thresholds of 50 and 200 mV (**Figure 1**). The 6-mΩ sense resistor, R_S, allows a nominal slow-comparator trip at 8.3A for overload conditions and a fast-comparator trip at 33.3A for short circuits. Only circuit resistances limit the initial short-circuit current spike during a period that includes the fast-comparator delay and the 30 μsec it takes to complete interruption of the short circuit by discharging M_1's gate capacitance. Various elements, such as R_S and the on-resistance of M_1, contribute to the circuit resistances. The waveform recorded during a short circuit indicates a peak current of 400 from the 2.4V peak across R_S, decreasing to 100A in 28 μsec (**Figure 2**).

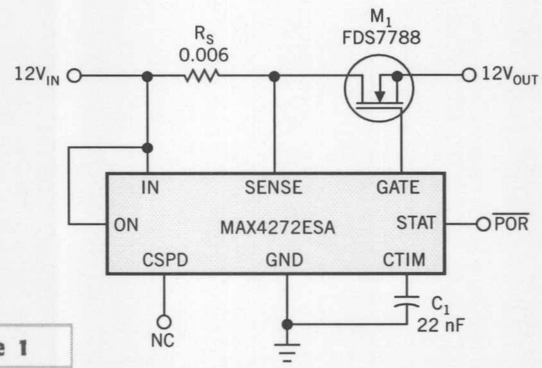

Figure 1

A typical hot-swap controller circuit exhibits a 30-μsec short-circuit current pulse of 400A peak.

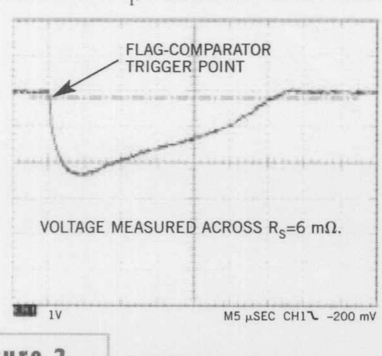

Figure 2 **The short-circuit current in Figure 1 is 400A, decreasing to 100A in 28 μsec.**

You can limit the short-circuit current duration to less than 0.5 μsec by adding a Darlington pnp transistor, Q_1, to speed the gate discharge (**Figure 3**). D_1 allows the gate to charge normally at turn-on, but, at turn-off, the controller's 3-mA gate-discharge current is directed to the base of Q_1. Q_1 then acts quickly to discharge the gate, in less than 100 nsec. Thus, the high-current portion of the short circuit is limited to slightly more than the fast comparator's delay time of 350 nsec. The apparent reverse overshoot current and the steep rise in the waveform of **Figure 4** arise from parasitic series inductance in the sense-resistor chip. The circuit of **Figure 5** can limit short-circuit current to approximately 100A for less than 200 nsec. The pnp transistor, Q_{1A}, which triggers when the voltage across R_S reaches approximately 600 mV, drives the npn transistor, Q_{1B}, to quickly discharge M_1's gate capacitance. The steep voltage waveform aids quick triggering of the pnp transistor.

The oscilloscope's ground lead introduces an artifact, which appears as the leading-edge oscillation in **Figure 6**. Again, as in **Figure 4**, the apparent reverse-overshoot current and the steep rise in the waveform of **Figure 6** arise from parasitic series inductance in the sense-resistor chip. C_2 connects between the gate and source of M_1 to reduce the positive-transient step voltage applied to the gate during a short circuit. Zener diode D_1 reduces $I_{D(ON)}$ by limiting V_{GS} to less than the 7V available from the MAX4272. Although D_1

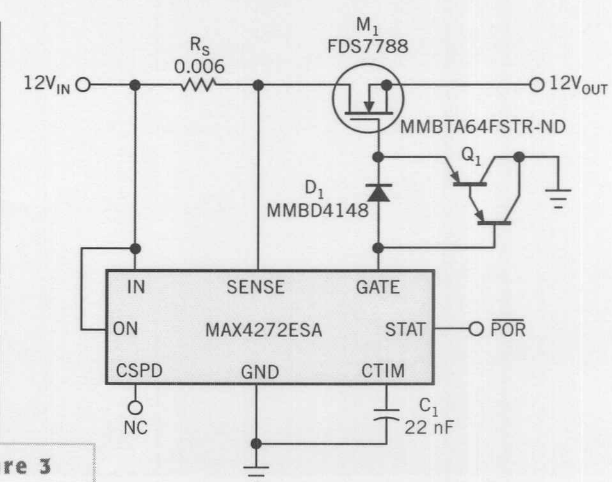

Figure 3

The addition of Q_1 increases the gate-pulldown current, limiting the short-circuit-current duration to less than 0.5 μsec.